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DIFFUSIVE METRICS INDUCED BY MULTIAFFINITIES. THE COVID-19 SETTING FOR BUENOS AIRES (AMBA)

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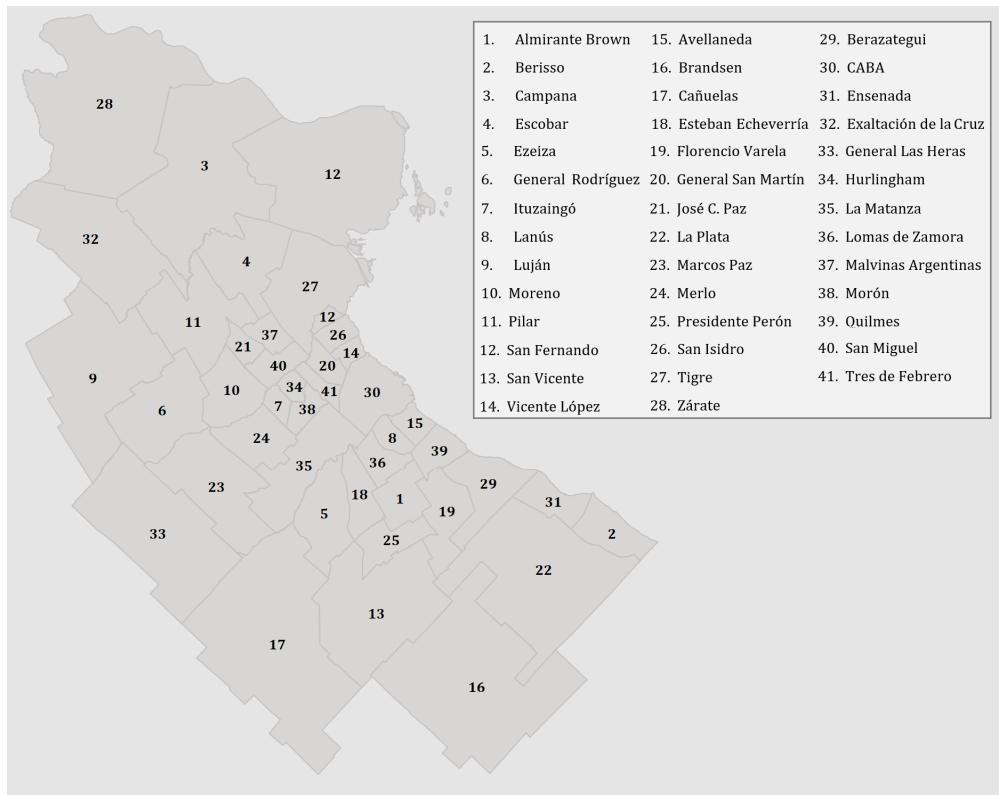
Abstract: In this work we aim to use tools of discrete harmonic analysis in order to provide a metric in the set of the 41 cities belonging to the largest urban concentration in Argentina based on public transport and neighborhood. The results can be applied to predict and control the spread of COVID-19 and other pandemic diseases in such a setting.

Keywords: *weighted graphs, diffusion, graph Laplacian, metrization, COVID-19, AMBA-Argentina*

2000 AMS Subject Classification: 90C35, 60J60, 54E35

1 INTRODUCTION

The acronym AMBA is used to name the 41 cities that concentrate one third of the total population of Argentina and is spatially concentrated around Buenos Aires City. The following map depicts their distribution.



Aside from the geographical distance between locations i and j in the map there is a valuable information given by the public transport system in AMBA. The system SUBE keeps a great amount of information that allows to have another geometry provided by a connectivity distance built on this big data source. With the idea of considering at once a diversity of affinities between two cities i and j , such as euclidean distance, neighborhood, public transport, private transport, etcetera, we introduce a diffusive metrization of the graph with 41 vertices that takes into account these diverse factors which all together contribute to the motion of people inside AMBA.

In Section 2 we introduce the metric based on the construction of Coifman-Lafon (see [1]) for a multiweighted undirected graph, through the spectral analysis of the Laplace operator determined by a convex combination of the affinities. Section 3 is devoted to apply the metric to the case of AMBA, by showing the families of metric balls computed using some of the data provided by the system SUBE.

2 METRIZATION OF MULTIWEIGHTED GRAPHS

Let $G_k = (V, E, \vec{a}, W^k)$, $k = 1, \dots, K$ be a finite sequence of undirected weighted graphs with the same set of vertices V , the same set of edges E and the same weight in each vertex $\vec{a} = (a_1, \dots, a_n)$, $a_i > 0$, $i = 1, \dots, n = \#(V)$. For each k , $W^k = (w_{i,j}^k : i, j = 1, \dots, n)$ determines the affinity of each pair i, j of vertices with respect to the feature k . We shall assume that \vec{a} and each W^k are normalized to probabilities, i.e. $\sum_{i=1}^n a_i = 1$, $\sum_{i,j=1}^n w_{i,j}^k = 1$, $k = 1, \dots, K$. Let $\vec{\theta} = (\theta_1, \dots, \theta_K)$ be a vector of length K with $\theta_k \geq 0$ for every k and $\sum_{k=1}^K \theta_k = 1$. Set $w_{i,j} = \sum_{k=1}^K \theta_k w_{i,j}^k$. The parameters θ_k can be chosen according to our perception of the relevance of the k -th feature for the construction of the metric.

The main result of this section is contained in the following statement and makes use of the Coifman-Lafon diffusive metrization scheme. See [1] and [2], for a different approach to metrization see [3].

Proposition 1 Let G_k be as before, $k = 1, \dots, K$ and $\theta_k \geq 0$ with $\sum_{k=1}^K \theta_k = 1$. Then for $t > 0$ the function $d_t(i, j) = \sqrt{\sum_{\ell \geq 0} e^{2t\lambda_\ell} |\phi_\ell(i) - \phi_\ell(j)|^2}$ is a metric on V , where $(\lambda_\ell, \phi_\ell)$ is the spectral resolution of the Laplacian $\Delta f(i) = \frac{1}{a_i} \sum_{j=1}^n w_{ij} (f(j) - f(i))$ where $w_{i,j} = \sum_{k=1}^K \theta_k w_{i,j}^k$.

3 THE CASE OF AMBA WITH NEIGHBORHOOD AND PUBLIC TRANSPORT

With the above notation, $V = \{1, \dots, 41\}$ represents the 41 cities that constitute AMBA, with W^1 reflecting the data provided by SUBE and W^2 the fact that two cities are neighbor to each other. Here we show only a small part of the unnormalized matrix W^2 .

Figure 1: Unnormalized submatrix of W^2 (20×41)

¹In the next page we exhibit the full unnormalized form of W^1 .

0	7	0	19	808	10	16	6223	5	54	24	45	1843	417	3745	55	53	4183	3551	135	22	482	12	60	5915	184	81	2	612	34539	4	0	1	30	1048	20782	32	206	8355	35	163	
7	0	0	3	0	7	0	2	1	0	1	2	11	2	0	5	31	0	0	7105	0	1	0	0	1	40	258	352	0	0	6	12	2	1	48	0	0					
0	0	0	846	0	24	1	2	31	227	17	0	27	1	0	1	1	12	30	4	5	3	0	37	211	1103	1	433	0	120	0	3	12	5	60	4	1	13	1			
19	0	846	0	6	103	23	15	29	618	5626	529	1	1635	15	0	0	22	14	252	1435	14	3	62	3	4235	0	90	0	67	90	100	120	72	16	982	102					
808	3	0	6	0	2	14	1021	1	39	8	16	178	76	498	1	1003	7551	222	36	12	44	46	298	54	22	2	64	7537	5	0	0	9	958	2685	11	49	214	71			
10	0	24	103	2	0	150	12	991	4470	1316	37	0	123	18	0	1	13	4	98	427	4	23	544	0	115	111	0	26	130	220	31	66	267	4	203	146					
16	0	1	23	14	150	0	31	20	2938	64	28	3	142	22	0	2	45	11	140	104	11	81	4467	4	199	65	0	5	6070	0	0	1	885	1482	78	65	6420	18	429		
6223	7	2	15	1021	12	31	0	2	74	30	35	515	321	10406	14	60	2292	1898	146	37	264	9	142	720	165	86	1	486	39521	7	3	0	23	971	19166	40	99	4146	39	226	
5	0	31	29	1	991	20	2	0	695	266	4	0	16	8	0	0	4	1	20	108	5	3	126	0	108	18	8	1	949	1044	1	53	38	6	41	10					
54	2	31	618	39	4470	2938	74	609	0	3424	620	4	1727	115	0	9	63	28	1578	5041	40	279	7911	7	1666	2177	3	32	22871	2	35	277	227	214	1309	5152	52	7601	2064		
24	1	227	5626	8	1316	64	30	266	3242	0	309	4	2188	44	0	1	25	29	430	3588	24	10	277	1	1719	2481	20	10	7229	1	493	0	227	197	77	4031	247	32	1676	430	
45	0	17	529	16	37	28	35	4	620	309	0	2	2223	48	0	0	36	43	271	424	20	5	74	5	7362	9170	5	21	5958	1	1	0	34	197	124	622	63	45	529	98	
1843	1	0	1	178	0	3	515	0	4	2	0	28	236	368	12	321	65	8	2	54	0	6	936	9	7	0	39	2679	2	0	0	4	73	966	1	7	104	0	18		
417	2	27	1655	76	123	142	321	16	1727	2188	2223	28	0	249	0	10	313	284	6142	1843	85	22	647	68	10087	4845	13	129	44844	5	10	3	217	1738	1071	5817	265	327	1407	1061	
3745	11	1	15	498	18	22	10406	8	115	44	48	236	266	249	0	7	24	988	2515	129	51	670	4	155	364	144	66	3	1954	36523	11	0	0	31	527	3538	49	106	1033	45	144
55	2	0	0	1	0	0	14	0	0	0	0	0	368	0	7	0	9	15	0	0	103	0	1	30	0	0	0	6	57	0	0	0	2	35	1	0	1	0	2		
53	0	1	0	1003	1	2	60	0	9	1	0	12	10	24	0	0	307	10	2	0	10	35	11	18	3	2	0	5	549	0	0	0	1	954	161	0	13	23	0	19	
4183	5	1	22	7521	13	45	2952	4	63	25	36	131	988	9	307	0	460	158	25	146	8	302	299	188	84	218	16876	1	0	0	82	11399	26	295	572	23	181				
3551	31	1	14	222	4	11	1898	1	28	29	43	65	284	2515	15	10	460	0	92	19	2509	1	26	72	179	60	1	6772	21292	46	0	0	23	403	1960	27	87	11126	26	119	
135	0	12	252	36	98	140	146	20	1578	430	271	8	6142	129	0	2	158	92	0	1295	50	24	615	30	6059	1615	12	50	26014	1	0	0	947	1512	533	822	1010	103	1430	12210	
22	0	30	1435	12	427	104	37	108	5041	2	1843	51	0	0	25	19	1295	0	17	9	163	0	1314	3286	12	6	10500	0	25	0	605	284	364	4783	712	26	11265	1595			
482	7105	4	14	44	4	11	264	5	40	24	54	85	670	103	10	146	2509	50	17	0	2	50	58	55	47	2	3040	8465	4337	0	2	17	198	455	46	88	2410	21	43		
12	0	5	3	4	23	81	9	3	195	10	5	0	22	4	1	24	9	2	0	2196	1	17	0	0	3	1101	0	0	123	41	646	13	3	257	1	15	92				
60	1	3	62	46	544	4467	142	126	7911	277	74	6	647	155	1	11	130	26	615	163	50	2196	0	11	436	235	0	32	26468	0	4	139	671	8217	293	308	12490	63	311	1672	
5915	0	0	3	298	0	4	270	0	7	1	5	936	68	364	30	18	299	72	30	0	58	1	11	0	39	5320	1	0	0	94	1273	5	18	136	7	35					
184	0	37	2047	54	115	166	18	1719	7362	9	10687	144	0	3	188	179	6059	1314	55	17	436	39	0	7521	6	74	12837	1	18	0	310	519	3194	394	839	1060	3462	531	156		
81	0	211	5772	22	111	65	86	18	2172	2481	9170	7	4845	66	0	2	84	60	1615	3826	47	10	255	20	7521	1	187	0	3	6661	299	75	3068	441							
2	1	1103	122	2	7	0	1	8	3	20	5	0	13	3	0	0	2	12	12	2	0	0	6	59	0	2	465	0	10	0	0	5	6	10	2	1	4				
612	40	1	3	64	546	4235	7537	2198	6070	39291	949	22871	7229	5958	3629	57	16876	21292	26014	10500	8465	11010	26468	5330	1237	48557	0	137	237	5857	14	2567	1604								
1048	6	12	90	958	220	1482	971	38	2727	197	73	1738	527	2	554	3783	403	1512	284	199	646	8217	94	1017	519	5	198	88221	4	1	11	1090	0	3635	176	18829	476	473	8905		
20782	12	5	100	2685	31	78	19166	6	214	77	124	966	1071	3338	35	161	11399	1560	533	86	455	13	293	1273	506	394	6	549	45769	9	1	0	75	3635	0	123	351	5449	96	1019	
32	2	60	2631	11	66	65	40	15	1309	4031	622	1	5817	49	1	0	26	27	822	4783	46	3	308	5	3462	6661	10	27	8749	1	10	0	237	176	123	0	291	25	7029	414	
206	1	4	72	49	267	6420	99	55	5152	247	63	7	265	106	0	13	255	87	1010	712	88	257	12490	18	531	299	2	69	21285	0	4	17	5857	18829	0	108	1696	4405	414		
8355	48	1	16	214	4	18	4146	6	52	32	45	104	327	10313	1	23	572	1126	103	26	2410	1	63	136	156	46	1	14	476	5449	25	108	0	31	129	2408	0	31	0	2408	1604
35	0	13	982	12	203	419	39	41	1696	1076	529	0	1407	45	0	0	23	26	1490	11665	21	15	311	7	1060	3068	4	10	13912	0	16	0	2567	473	96	7029	1196	31	0		
163	0	1	102	71	146	484	226	10	2064	430	98	18	1061	144	2	19	119	1220	1595	43	92	1672	35	859	441	6	65	32648	0	4	3	1604	8905	1019	4405	129	2408	0			

Figure 2. Matrix that reflects

Let us only illustrate some d_t -balls for $t = 0.25$ with $\theta_1 = \theta_2 = \frac{1}{2}$ and two different weights \vec{a} : the uniform $\vec{a}_u = (\frac{1}{41}, \dots, \frac{1}{41})$ and

$$\vec{a}_d = (0.0023, 0.0009, 0.0004, 0.0014, 0.0015, 0.0009, 0.0012, 0.0030, 0.0007, 0.0009, 0.0011, 0.0015, 0.0008, 0.0016, 0.0049, 0.0005, 0.0006, 0.0018, 0.0015, 0.0031, 0.0013, 0.0008, 0.0012, 0.0010, 0.0019, 0.0022, 0.0014, 0.0006, 0.0019, 0.0095, 0.0011, 0.0004, 0.0015, 0.0018, 0.0018, 0.0026, 0.0013, 0.0018, 0.0029, 0.0018, 0.0034)$$

which is a normalization of the density of the disease in each location (total number of active infections over population) by July 2020. The algorithms is implemented in Python.

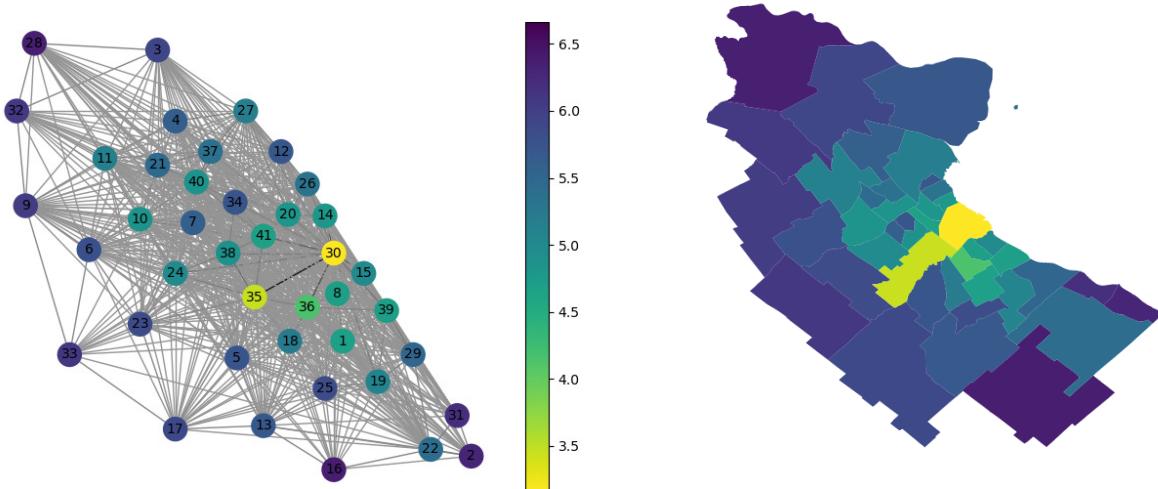


Figure 3: Weight \vec{a}_u . Balls centred at CABA. Growing radii according to the scale of colors. Left: Graph, Right: map.

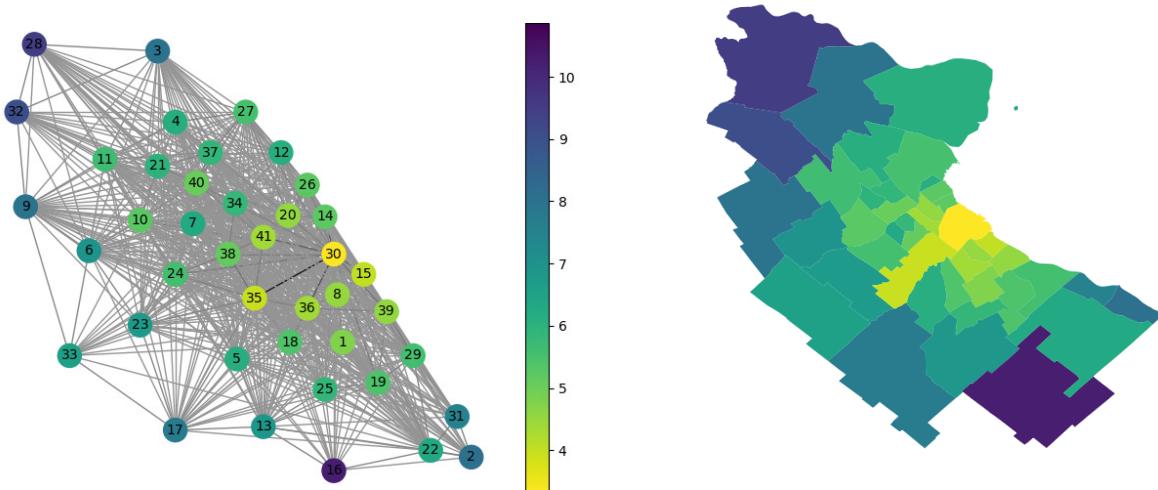


Figure 4: Weight \vec{a}_d . Balls centred at CABA. Growing radii according to the scale of colors. Left: Graph, Right: map.

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